Section 1: Introduction

In the nearly fifty years since the Soviet Union launched Sputnik, there has been a steady growth in the number of countries that have launched satellites into orbit. Growing even faster is the number of countries that have deployed satellites launched by others. Currently, satellites serve a multitude of civilian and military functions, from facilitating communications and weather forecasting to providing highly accurate navigational information, and many nations envision making future investments in satellites for such uses.

In the U.S. military there is also a growing interest in basing weapons in space as well as in developing means to attack the satellites of other nations and to protect U.S. satellites from attack. While space has long been home to military systems for observation, communication, and navigation, these new missions would be a departure from long-held norms. There are currently no known weapons stationed in space that are explicitly designed to apply force. Nor are there any known deployed systems designed explicitly to destroy satellites, either from the ground or from space.

This shift in U.S. military thinking is evident from planning documents released in recent years that envision a restructuring of military commands and the development and deployment of anti-satellite weapons and space-based weapons.[1] These new systems are meant to fulfill four general missions:

- defending U.S. satellites and ensuring U.S. freedom to operate in space
- denying adversaries the ability to use space assets
- intercepting ballistic missiles using space-based interceptors
- attacking targets on the ground or in the air using space-based weapons

The first two missions reflect the military importance of current U.S. space-based systems. This utility has led to a desire to protect these systems and to deny similar capabilities to potential adversaries. The third mission, an ongoing interest of many missile defense proponents, is leading toward the deployment of prototype weapons as part of a space-based "test bed." The fourth mission, which has attracted considerable public attention and concern, currently appears to be of less interest to the U.S. military than the other missions.

1. See, for example, *Report of the Commission to Assess United States National Security, Space Management and Organization*, January 11, 2001, http://www.fas.org/spp/military/commission/report.htm, accessed February 8, 2005, and Air Force Space Command, "Strategic Master Plan: FY06 and Beyond," October 1, 2003, http://www.peterson.af.mil/hqafspc/news/images/FY06%20Beyond%20Strategic%20Master%20Plan.pdf, accessed February 8, 2005.

U.S. interest in new types of weapons has spawned an emerging international debate. Key topics include whether the deployment of space-based weapons and anti-satellite weapons is inevitable, what military utility such weapons would have, how their deployment would affect the security of the owner nation and the wider international community, whether their deployment and use would interfere with other military and civilian uses of space, and what normative and legal constraints on the use of space could be agreed upon and enforced.

Addressing these issues requires assessing a wide range of political, diplomatic, military, and technical issues. This report is limited to a discussion and analysis of the technical and military issues and focuses on a number of key questions: What capabilities could anti-satellite weapons and weapons in space realistically provide? Would these capabilities be unique? How do they compare with alternatives? What would they cost? What options would be available to nations seeking to counter these capabilities? The answers depend on technical realities that must be considered in any policy analysis of space weapons and anti-satellite weapons. Unless debate about these issues is grounded in an accurate understanding of the technical facts underlying space operations, the discussion and policy prescriptions will be irrelevant or, worse, counterproductive.

In evaluating proposed military systems, it is important to distinguish between constraints imposed by financial cost, by technology, and by physics. The cost of operating in space is often high relative to the cost of operating in the air or on the ground. While cost will be important in considering development and deployment, it may not be decisive if the system could provide a unique capability that is deemed important. Available technology places important limits on what systems are currently feasible for a given country, but those limits can change over time and do not represent fundamental limitations. The space-based laser, for example, has so far achieved power levels well below what is required for a usable weapon, but there do not appear to be fundamental limits to increasing its power over time. Physics, on the other hand, places fundamental limits on space operations that will not change with time. An example of a fundamental limit posed by physics is the fact that satellites in low orbits cannot remain stationary over a given location on Earth, so multiple satellites are required to ensure that one is always near that location.

This report provides information on a range of technical issues related to space systems that are important for anyone involved in the debate over space security to understand.[2] It discusses issues of cost and technology, where

2. Other books and articles that address technical issues related to space security include Ashton B. Carter, "Satellites and Anti-Satellites: The Limits of the Possible," *International Security* (Spring 1986): 46-98; Richard L. Garwin, "Space Technology: Myth and Promise," 1988, http://www.fas.org/rlg/myths-of-space.htm, accessed February 8, 2005; Michael J. Muolo et al., *Space Handbook, Volume 1: A War Fighter's Guide to Space*, (Maxwell Air Force Base, AL: Air University Press, December 1993), http://www.au.af.mil/au/awc/awcgate/au-18/au180001.htm, accessed February 8, 2005; Michael J. Muolo et al., *Space Handbook, Volume 2: An Analyst's Guide*, (Maxwell Air Force Base, AL: Air University Press, December 1993); Office of Technology Assessment, *Anti-Satellite Weapons, Countermeasures, and Arms Control*

appropriate, and attempts to separate these from the fundamental issues of physics. It is written for a lay audience but includes appendices that give more detailed technical information for specialists. The report is also intended to familiarize readers with the important technical terminology and concepts related to satellites and operating in space. For example, the behavior of objects traveling at very high speeds in space is much different than the behavior of objects in motion on the ground or in the atmosphere and is largely outside day-to-day human experience. As a result, most people have not developed intuition about the behavior of satellites, so that attempting to apply lessons from common experience can lead to mistakes and misconceptions. In addition, the report shows that a few basic laws of physics have important implications for the way satellites, space-based weapons, and anti-satellite weapons can be designed and operated. It explains these underlying physical principles and discusses their implications.

The report addresses technical issues that are relevant to space policy, but does not address policy issues per se or make policy recommendations. The report is not intended to be comprehensive; the omission of a topic should not be construed to mean the topic is not important.

Sections 2 and 3 lay out the main points of the paper. Section 2 presents the report's findings and conclusions that have implications for space policy and directs the reader to the sections from which these conclusions are derived. Section 3 summarizes the main technical points made in the subsequent sections.

Sections 4 through 8 discuss basic concepts and implications of orbital dynamics; Section 4 covers the basics of satellite orbits; Section 5 inventories the types of orbits and the criteria for choosing a particular orbit; Section 6 discusses the physics of maneuvering in space; Section 7 assesses the implications of this maneuvering for satellite mass; and Section 8 discusses the physics and technology of launching mass into space and placing satellites in orbit.

Section 9 examines the implications of these technical assessments for several specific space-based systems—in particular, space-based constellations of ground-attack weapons, space-based missile defense interceptors, and the military space plane.

The final three sections discuss interference with satellite operations. Section 10 identifies and discusses the various components that constitute a

(Washington, DC: Government Printing Office, 1985); Philip E. Nielsen, *Effects of Directed Energy Weapons*, (National Defense University, 1994), http://www.ndu.edu/ctnsp/directed_energy.htm, accessed December 23, 2004; James Oberg, *Space Power Theory*, 1999, http://www.jamesoberg.com/spt.html, accessed February 8, 2005; Bob Preston et al., *Space Weapons Earth Wars* (Arlington, VA: RAND Project Air Force, 2002) http://www.rand.org/publications/MR/MR1209/, accessed February 8, 2005; *Report of the American Physical Society Study Group on Boost-Phase Intercept Systems for National Missile Defense*, July 2003, http://www.aps.org/public_affairs/popa/reports/nmd03.html, accessed February 8, 2005; *Air University Space Primer*, August 2003, http://space.au.af.mil/primer/, accessed February 8, 2005; Federation of American Scientists' Panel on Weapons in Space, *Ensuring America's Space Security*, September 2004, http://www.fas.org/main/content.jsp?formAction=297&contentId=311, accessed February 8, 2005; Bruce M. DeBlois et al., "Space Weapons: Crossing the U.S. Rubicon," *International Security* (Fall 2004): 1–34.

satellite system, because different methods of interference target different components. Section 11 gives an overview of many of the possible means to interfere with a satellite system. Section 12 looks in more detail at three particular topics related to interference: space-basing of anti-satellite (ASAT) weapons, a simple ASAT that would place debris in the path of a satellite, and ways to mitigate satellite system vulnerability.